

RAPID SOIL STABILIZATION AND STRENGTHENING USING ELECTROKINETIC TECHNIQUES

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ABSTRACT

The Army has a requirement to develop methods of strengthening soil to support rapid runway and roadway construction. A study was undertaken on the use of DC current applied to soil to form cementing phases in the soil. Preliminary work was on the use of zinc, aluminum, and iron in a variety of granular materials. Metal ions primarily form soft metal hydroxide gels that produce no immediate soil strengthening. Passing current through soil mixed with an alkali-reactive silicate produces rapid hardening with strength to 2,000 psi.

1. INTRODUCTION

Conventional soil strengthening typically involves the addition of cementing materials such as calcium hydroxide or portland cement. The primary objective is to produce a cementing phase such as calcium silicate hydrate, calcium carbonate or calcium sulfate (Rollings and Rollings, 1996).

The major problem with additives relates to the time required for the cementing phases to form and gain strength. Additionally, the cementing phases may not be stable and may slowly dissolve as water percolates through the soil. Conventional soil cementation may require one to three months to develop its ultimate strength. Developing rapid methods of soil strengthening are needed if the Army is to address the problems related to rapid airfield construction. A Science and Technology Objective (III. EN. 2002.01) has been established to address this requirement.

Passing an electric current through a fine-grained soil produces several different effects. The movement of current produces a net fluid flow toward the cathode (electro-osmosis). Ion and pole-molecules will move in the electrical field (electromigration). Charged particles will migrate in the electrical field (electrophoresis). The aqueous solution in the pore space can be broken down by the passage of current to alter the composition of the saturated soil (electrolysis). The electrical resistance of the soil results in the production of heat in the soil that

drives off volatile organic constituent and water present in the soil pore space. (Alshawabkeh, 2001). Additionally, the elevated temperature in the soil accelerated on-going chemical reactions in the soil.

Some changes produced by electric current moving in the soil can result in soil cementation and soil strengthening. During early work on dewatering soil it was noted the migration of cations from metallic electrodes could result in the formation of cementing phases in the surrounding soil (Casagrande, 1948, 1949, 1952). The advantage of this type cementation is that the cementing phase hardens quickly, strengthening the soil and can be produced in specific locations in the soil.

2. METHODS AND MATERIALS

The goal of this research project is to determine if cementation can be produced by altering the metal ion available and the type of electrolyte in the soil pore space.

In the first phase of the investigation methods and materials, the reaction of three metal anode and two electrolytes were investigated. The granular media used included quartz sand, glass bead, kaolinite, and montmorillonite. The granular media were selected on the basis of their stability and to provide a variety of soil types for experimentation. Table 1 summarizes the experimental systems that were investigated.

Table 1
Experimental Setup for Electrolytic Soil Treatment

Anode	Electrolyte	Medium
Zinc metal	Sodium phosphate	Quartz sand
Zinc metal	Sodium phosphate	Glass beads
Aluminum metal	Sodium phosphate	Quartz sand
Aluminum metal	Sodium chloride	Glass beads
Aluminum metal	Sodium chloride	Montmorillonite
Aluminum metal	Sodium chloride	Kaolinite
Iron metal	Sodium carbonate	Glass beads

Report Documentation Page			Form Approved OMB No. 0704-0188	
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1. REPORT DATE 00 DEC 2004	2. REPORT TYPE N/A	3. DATES COVERED -		
4. TITLE AND SUBTITLE Rapid Soil Stabilization And Strengthening Using Electrokinetic Techniques			5a. CONTRACT NUMBER	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Corps of Engineers, Engineer Research and Development Center, Champaign, IL 61826; US Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS 39180			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited				
13. SUPPLEMENTARY NOTES See also ADM001736, Proceedings for the Army Science Conference (24th) Held on 29 November - 2 December 2005 in Orlando, Florida. , The original document contains color images.				
14. ABSTRACT				
15. SUBJECT TERMS				
16. SECURITY CLASSIFICATION OF: a. REPORT unclassified			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 5
b. ABSTRACT unclassified			c. THIS PAGE unclassified	19a. NAME OF RESPONSIBLE PERSON

All reactions were set up in a 2-in. \times 2-in. polyethylene test cell (Figure 1). The metal anode was buried in the granular medium and the first cell was flooded with the test electrolyte. All electrolytes were prepared as oil molar solutions. In all cases a carbon rod was used as cathode and was immersed in a fluid reservoir at the end of the test cell. A 20-volt DC potential was applied across the cell and the voltage was allowed to vary as the resistance of the cell changed. The fluid reservoir was separated from the granular medium using a perforated polyethylene plate covered with a nylon-polypropylene filter fabric.

The presence of a hard-cemented phase was determined by using a metal needle to conduct a simple penetration test (Figure 2). Products formed in the granular medium were identified based on the mineralogy. The mineralogy of the sample was determined using X-ray diffraction (XRD) analysis. XRD patterns were run on each of the samples, and were run as randomly oriented packed powders. A Philips PW1800 Automated Powder Diffractometer system was used to collect the XRD patterns employing standard techniques for phase identification. The run conditions included Cu K α radiation and scanning from 2 to 65 $^{\circ}2\theta$ with collection of the diffraction patterns accomplished using the PC-based, Windows-based version of DataScan, and analysis of the patterns using the Jade program from (both from Materials Data, Inc.). In preparation for XRD analysis, a portion of the sample was ground in a mortar

and pestle to pass a 45- μ m mesh sieve (No. 325). Bulk sample random powder mounts were analyzed using XRD to determine the mineral constituents present in each sample.

The crystal morphology and the distribution of amorphous and crystalline phases (Figure 3) were examined using images of fractured surfaces obtained from the hardened cement made using the ElectroScan Environmental SEM Model 2020 with a cerium hexaboride (CeB₆) electron source and a gaseous secondary electron detector (GSED). The imaging conditions used an accelerating voltage of 20 to 30 KeV and 1.81 mA, and approximately 5 Torr (666 Pa) water vapor in the sample chamber. The imaging gas was vaporized deionized water supplied via a digitally controlled needle valve assembly contained in a sealed Erlenmeyer flask located outside the sample chamber. Images of these samples were collected over a period of 30 seconds, and stored as 1 MB TIF files. Samples of granular material that were recovered intact were test to determine unconfined compressive strength using a Tinius-Olsen Compression Testing System.

In a second phase of the investigation pure quartz sand was mixed in a 50/50 proportion of calcium-rich slag (GranCem, Holcim US). The electrolyte used a saturated sodium chloride solution. The electrolyte was altered by passing a 20-volt DC current through the mixture with a pair of carbon electrodes (Figure 4).

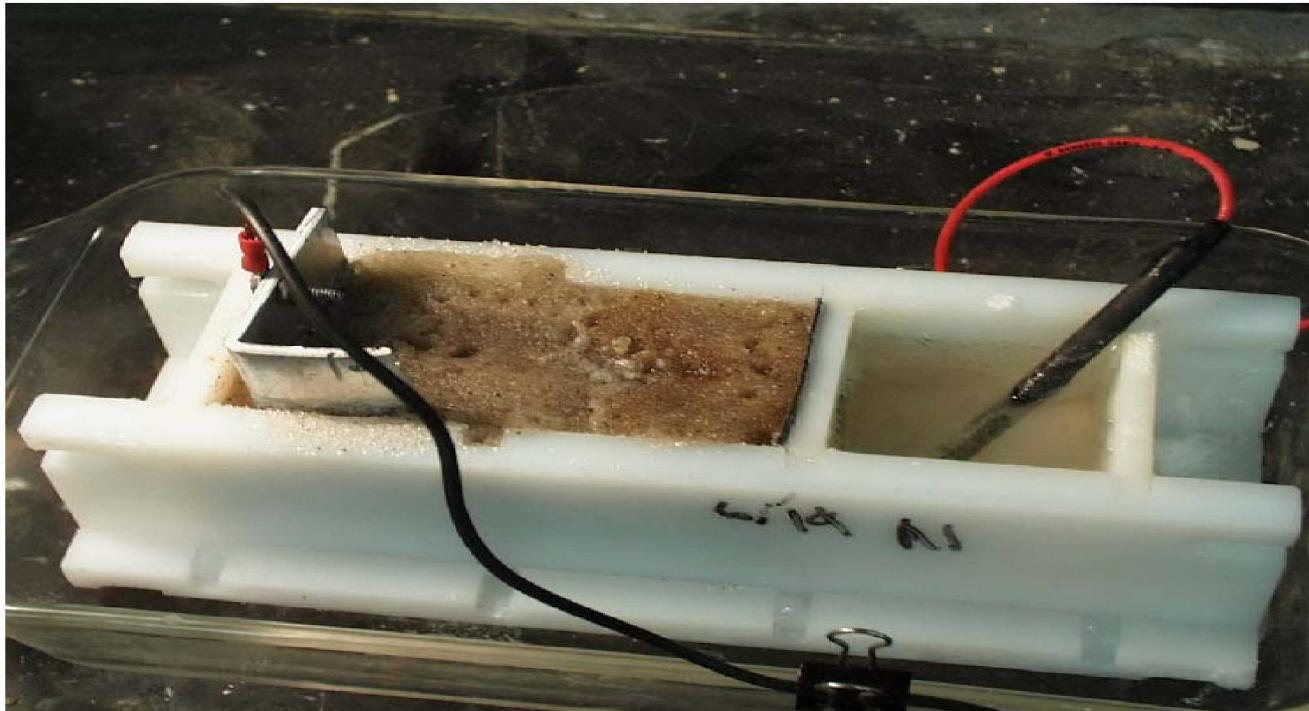


Figure 1. Test cell setup using this investigation

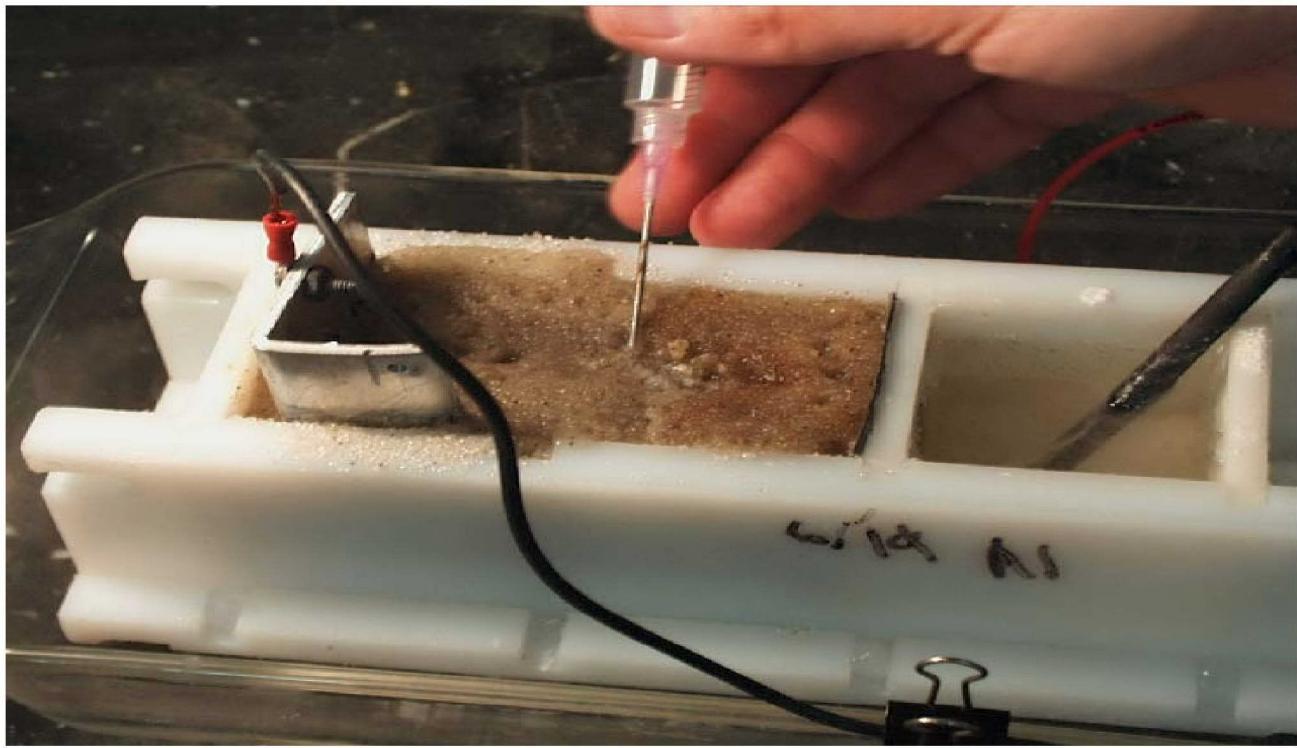


Figure 2. Penetration testing using a test needle

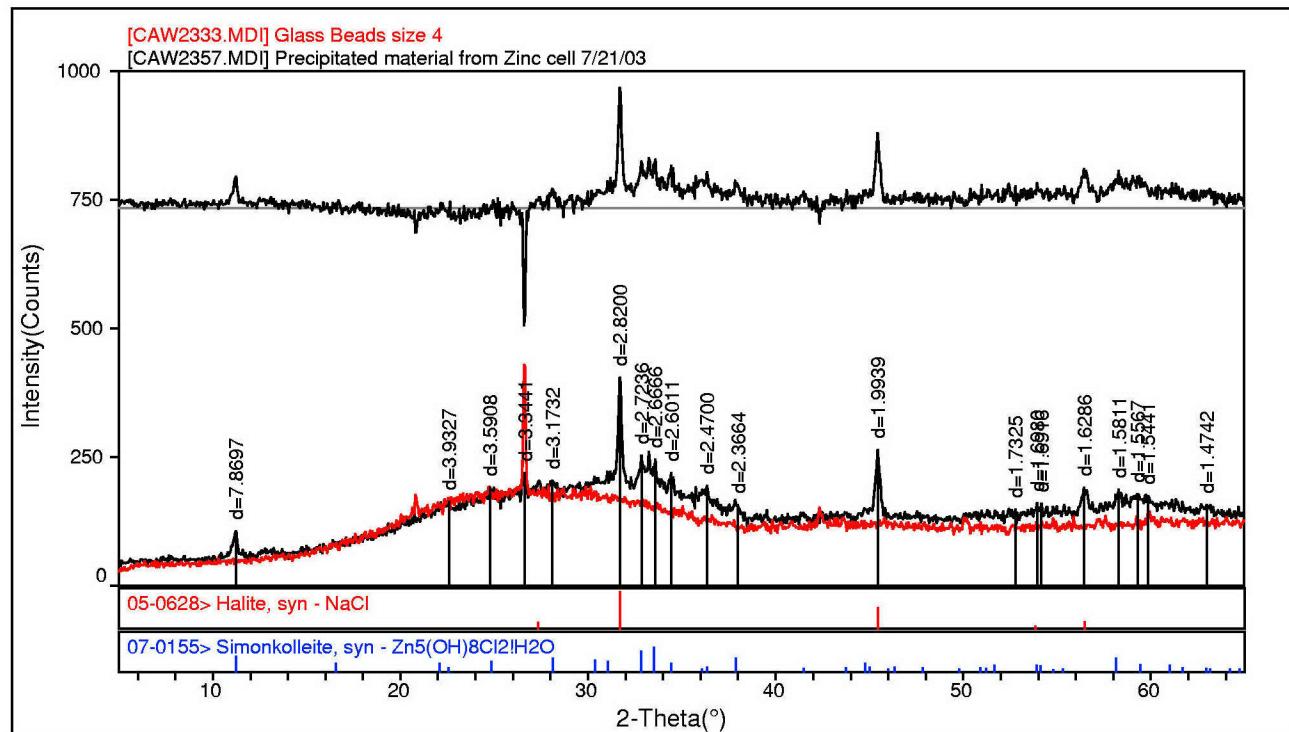


Figure 3. X-ray diffraction pattern showing Simonkolleite produced from a zinc electrode reaction. The lower curve (red) shows the pattern of the granular media used, which were glass beads in this case.



Figure 4. Test cylinder generated using slag/sand mixtures

3. RESULTS

Table 2 summarizes the results of the investigation. The hardened granular media produced by passing current through the test cells were cemented largely by complex hydroxide and halite. The compounds produced by the passage of current in the non-reacting media (quartz, glass, and clays) were relatively weakly cemented. The reactive mixture, slag, and sand, produced very strong cementation.

The slag and sand reaction is similar to reactions observed by adding sodium hydroxide to ground granulated slag (Talling and Brandstetr, 1989). This cementation system is characterized by the formation of calcium silicate hydrate and a rapid strength gain.

CONCLUSIONS

The major conclusions that can be drawn from these investigations are:

- a. The phases produced from metal anodes in non-reactive (quartz, glass or clay) media were chlorides and complex hydroxides.

- b. The types of metallic anodes governed the type of hydroxide formed.
- c. The type of electrolyte had a detectable effect on the anode the time occurred in the cementing material.
- d. The reactive medium (slag and sand mixture) reacted with the hydroxide formed during the passage of current and was strongly cemented.
- e. The most effective soil cementation system involves adding a reactive compound such as calcium-rich slag to the soil.

Electrokinetic production of cementing in soil offers unusual advantages in that it can produce rapid, highly directed development of cementing phases in soil using relatively inexpensive materials. Electrokinetically produced cementation can be used to simultaneously dewater soil as the cementing reaction proceeds. The use of electrokinetics systems in cementing pilings is particularly useful because any electrically conductive piling can become an electrode in the cementing system.

Table 2
Results from Electrolytic Treatment of Soil

Anode/ Electrolyte	Medium	Product	Cementation Ranking
Zinc/phosphate	Quartz	Zinc hydroxide	Soft
Zinc/phosphate	Glass beads	Zinc hydroxide	Soft
Aluminum/phosphate	Quartz	Aluminum hydroxide	Soft
Aluminum/chloride	Glass beads	Simonkolleite	Hard
Aluminum/chloride	Montmorillonite	Halite	Hard
Aluminum/chloride	Kaolinite	Halite	Hard
Iron/carbonate	Glass beads	Iron hydroxide (amorphous)	Soft
Carbon/chloride	Slag and sand	Hard calcium silicate hydrate	Very hard (2,000 psi)

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